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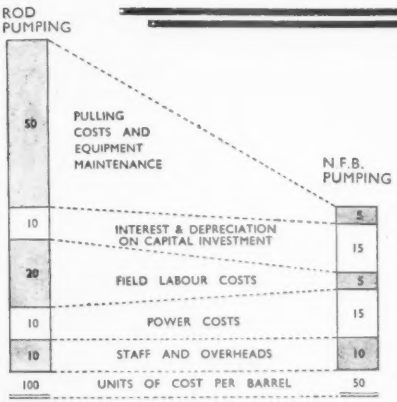


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# INSTITUTE OF PETROLEUM REVIEW

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## VERTICAL AIR PHOTOGRAPHS AS A GEOLOGICAL TOOL

*By* N. L. FALCON*

THE main principle guiding geological work in oil exploration is still the search for structures suitable for the accumulation and trapping of crude oil. Although other factors, such as the presence of porous rocks and likely source beds of marine or estuarine origin, play an important part, the choice of a drilling location must ultimately depend on structure.

The work of the petroleum geologist, therefore, is primarily concerned with the investigation of structure. He maps the outcropping rocks with as much detail as the local circumstances require, and to do that work he employs all the tools available to him. These tools may be normal geological tools, such as the study of fossils and minerals present in the rocks, or they may be tools borrowed from other branches of science. Thus the necessity for recording his observations on a map so that they will be readily available for use, demands a knowledge of topographical surveying. In cases where detailed topographical work is necessary, the appropriate specialist is called in (the topographical surveyor), as it would be uneconomic in such a case to misemploy geologists for this work. Even sub-surface geology, sometimes called exploitation geology, is largely directed towards an understanding of structure, and continues, with the aid of borehole data, the study of the three-dimensional picture begun


* Anglo-Iranian Oil Co. Ltd.

by the field work on the surface. Similarly, the results of most geophysical work must be interpreted in terms of geological structure before they can be used in oil exploration.

Air photographs perform two very great services for the oil geologist, and it is important not to confuse them. The first is a topographical service, the photographs, or maps prepared from the photographs, being used to provide the essential topographical background on which to record the geological observations. The second is a geological service, in that air photographs can provide geological information which may be more readily obtained from them than by ground observation, or which can only be obtained from them.

Just as the field geologist requires a knowledge of topographical surveying in order to make maps which are sufficiently accurate for his purpose, but which usually do not approach the ideal accuracy of the topographical surveyor, in the same way it is essential for the geologist working on air photographs to understand the principles of photogrammetry (photogrammetry is the science of making accurate measurements from air photographs).

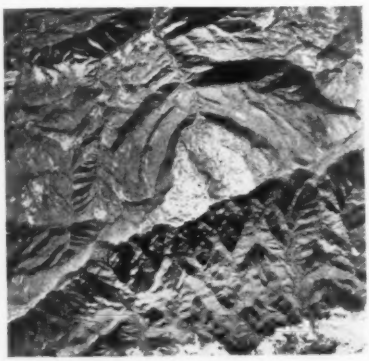
This distinction between the topographical function of air photographs and the interpretative function, that is the extraction of other scientific data from them, is fundamental, and is of course not confined to geology. A so-called "photo geologist" is a geologist with the necessary photogrammetrical experience who happens to be working for the time being on photographs. It is well to remember that while it takes several years of study, followed by a number of years of practical experience, to make a competent geologist, it takes only a matter of months for that geologist (providing he has normal stereoscopic vision) to acquire the photogrammetrical knowledge and experience he needs for working on photographs. The detailed practice of photogrammetry, for accurate topographical purposes, is left to the full-time air surveyor.

It follows, therefore, that it is impossible in one paper, or even one text-book, to describe the actual process of geological work on air photographs, because it would entail the production of several geological text-books. This will be readily understood when it is appreciated that there are several complete text-books devoted to geomorphology, itself merely one aspect of geological study, based on a much wider geological background. (Geomorphology is the study of the actual topography of the earth's surface, with the object of discovering how the various types of earth sculpture have been produced, and of interpreting their meaning in earth history.)

There are considerable advantages to the geologist in a bird's-eye view. Slight difference of topography or vegetation, changes of soil colour, peculiarities of drainage, and many other features which may be difficult or even impossible to appreciate on the ground, are often quite conspicuous from the air, and may provide important evidence for the unravelling of geological structure.

The aeroplane has been used for geological mapping for a number of years. At first the photographs were examined directly, either separately or grouped together in a mosaic. This method suffers from the great disadvantage of giving only a two-dimensional picture of the ground, with consequent difficulties of interpretation. It is easy, for example, on a single aerial photograph to confuse an object with its shadow, or mistake an elevation for a depression, or one may be unable to interpret an object at all (see Fig. 1). This difficulty was overcome by employing stereoscopy and introducing the third dimension, a method which is now used for geological mapping over wide areas.

When we look at a three-dimensional object we appreciate its form because we have binocular vision. Each eye sees the object from a slightly different viewpoint and, used independently, gives a flat picture of the object, like a photograph. It is the unconscious fusion of the two slightly different flat pictures by the brain which produces the three-dimensional space model of normal vision. Many readers will have experience of the stereoscopic camera, which, by means of two lenses a few inches apart, gives two photographs of any scene. When these two photographs are examined under a stereoscope they merge to give a single three-dimensional image, as in normal binocular vision. There is nothing very complicated about the stereoscope itself; it is merely an apparatus of mirrors, lenses, and prisms designed to allow the two images to be superimposed on each other without eye-strain.



[Photo by Fairchild Aerial Surveys Inc.

*Fig. 1.—Inclined strata in Santa Barbara County, California. The dip increases towards the top of the photograph. It is not easy to interpret photographs of this sort on a single print, because of shadow difficulties. Turn this page upside down and notice the difference. Shadow difficulties are overcome by using stereoscopic pairs and a stereoscope.*

Much stronger relief can be obtained by using an ordinary single lens camera, and taking two pictures of a distant view from positions about a hundred yards apart. This is the method used for taking aerial photographs for stereoscopic examination, except that the camera in the aircraft is pointing vertically downwards from a considerable altitude.

Any pair of successive photographs with an overlap is called a stereoscopic pair and can be examined under a stereoscope. The effect is rather startling to the uninitiated. The overlapping part of the photograph comes to life and the observer finds himself suspended, as in a helicopter, so that he can examine the country at his leisure.

One feature of the space model needs explanation; the exaggerated relief effect, caused by the wide separation of the points from which the two photographs were taken. The effect is similar to the picture a giant would see who was as high as the aeroplane, and whose eyes were as far apart as the distance travelled by the aircraft between the two exposures. This exaggeration of vertical scale of three or four times has advantages, in that it enables small topographical changes to be recognized, even the inclination of strata with dips as low as one degree. It is also of great assistance in differentiating vegetation by relative height. But vertical exaggeration also has disadvantages which need watching. It is almost an article of faith amongst petroleum geologists that profile sections should be drawn with the same horizontal and vertical scale to avoid distortion (you would not recognize your best friend if his profile was exaggerated, even twice, in one direction). The geologist must constantly bear this in mind when using his stereoscope, particularly when studying photographs of hilly country. The relief model he studies, and from which he draws his maps, must always be regarded with a certain amount of suspicion. He must remember that this apparent precipice is only a moderate

[Burmah Oil Co. Ltd.

*Fig. 2.—A photograph of an area in north-east India showing an intricate drainage pattern, and the pitching end of an anticline.*

[Burmah Oil Co. Ltd.

*Fig. 3.—A geological map made from the above photograph.*

slope, that these rocks are much flatter than they look. Changes in the apparent thickness of strata due to vertical exaggeration must be distinguished from genuine changes of thickness, and so on.

It is as dangerous for a geologist to look through a stereoscope and forget about the photogrammetric principles involved as it is for a photogrammetric expert to map geological lines without geological training and experience.

The procedure usually adopted in making geological maps from stereoscopic pairs of photographs is the direct tracing of detail on kodatrace (transparent material similar to cellophane with one matt surface) from the three-dimensional space model under the stereoscope (see Figs. 2 and 3). The individual tracings, or group of tracings made from short runs of photographs, are later assembled into a map by normal photogrammetric processes, the procedure used depending on the order of accuracy required.

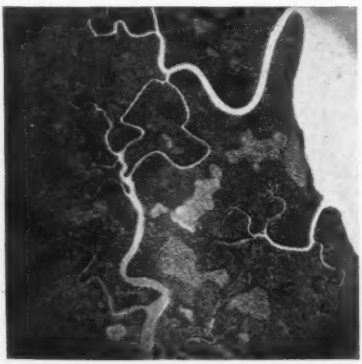
A map so made is a photo-geological interpretation, and is not regarded as the last word in the geological mapping of an area. It does not take the place of geological work on the ground, but assists and directs it. It is obviously necessary for geologists to hammer rocks on the ground to investigate their nature, but usually it is not necessary for them to spend their field time making a map to serve as a background for their observations.

The ideal organization of work is for an area to be photographed before detailed work is done on the ground or even before preliminary ground reconnaissance, if it is reasonably certain that the method will yield results. The ground parties will then be able to enter the field armed with a useful structural and topographical map which will enable them to plan their work to advantage. The photo-geological map should give the field parties such essential information as the position of the best stratigraphical exposures and the best localities for studying structural complications, besides referring them to areas where the interpretation is doubtful and needs checking. After the ground survey a final map is compiled, based on

field observation and photographic interpretation. Even if the preliminary map made from air photographs contains no geological information at all, but only selected topographical detail traced by a draughtsman, at an approximate scale, it forms a most valuable document for the field parties.

Not every area, of course, will yield good results by photo-geological methods. In some areas geological results may be entirely negative. The most sensational results are probably achieved in jungle country. Here the difficulties of travel and mapping on the ground may be almost insuperable; one literally cannot see the wood for the trees. The stereoscopic bird's-eye view in such cases may bring out features of topography and drainage which can readily be referred to geological structure by an experienced observer. A mosquito-bitten, leech-ridden field geologist might never be able to appreciate the structure at all, even after years of painstaking work. In any jungle survey a large proportion of the geologist's time before the days of aerial survey was spent recording topographical detail, particularly the plotting of streams and rivers. The photo-geologist can now do all this routine surveying beforehand in a fraction of the time (hours instead of weeks) allowing the field geologist to concentrate on geological work to obvious advantage (see Fig. 4). In jungle country covering soft tertiary strata, careful mapping of drainage systems, even to the smallest tributaries, may give more structural information than anything else. In desert country where geological outcrops are not obscured by vegetation or alluvium, it may be possible to make a reasonably accurate and complete geological map from air photographs, requiring the addition of only a relatively small amount of ground information. This will be readily understood by anyone with a knowledge of plane tabling (see Fig. 5).

*Fig. 5.—The pitching end of an anticline in barren semi-desert country in India.*



[*Burmah Oil Co. Ltd.*

*Fig. 4.—Part of a river system in jungle-clad country. The different types of vegetation are related to differences of subsoil. The geological examination of such areas on the ground is extremely difficult, and photographs are consequently of great assistance for topographical and geological purposes.*

Stereoscopic photo-geology is not confined to the drawing of qualitative two-dimensional maps. It is possible to examine the stereo-relief model quantitatively by means of a simple apparatus called a stereometer. The distance, in

the direction of flight, between two points of detail, measured on a vertical photograph, depends in part on the relative difference of altitude of the points on the ground, and it will differ slightly on the two photographs forming a stereoscopic pair. The stereometer measures these differences accurately on the relief model, from which, knowing the scale of the photographs and the length of the flying base, it is possible to calculate differences of height with tolerable accuracy. By this means the values of dips and the thickness of strata can be calculated, the vertical displacement of faults determined, and true scale profile sections constructed direct from the photographs. In favourable cases structural contour maps on any particular geological horizon can even be drawn. For various practical reasons, however, measurements of this sort for geological purposes are usually made on the ground, because ultimately their accuracy depends on geological field work.

## PERSONAL NOTES

*E. A. Evans*, President of the Institute, has been elected an Honorary Member of the Chemical, Metallurgical, and Mining Society of South Africa for the year ending June 30, 1949.

*T. F. Laurie*, F.Inst.Pet., a Member of Council of the Institute and chairman of the Finance Committee, will be taking up a new appointment as chairman of the Irish-American Oil Co. at the end of the year. Mr Laurie joined the Company in 1922, became its secretary in 1923, a director in 1931, and managing director in the same year. Towards the end of 1938 he was appointed a general sales manager of the Anglo-American Oil Co. in London and a few months later joined the International Association (Petroleum Industry) Ltd. During the war Tom Laurie was general sales manager of the Petroleum Board.

*L. W. Leyland Cole*, chief agricultural chemist for Shell Petroleum Co. Ltd., is going to East Africa at the invitation of the Insecticides Committee appointed by the Colonial Office. He will be visiting Kenya, Uganda, Tanganyika, and the Sudan to study means for combating tsetse flies, mosquitoes, and other insects.

*J. M. Pattinson*, A.M.Inst.Pet., general manager of fields and geological division of Anglo-Iranian Oil Co. Ltd., *R. S. Mackilligin*, F.Inst.Pet., technical manager of D'Arcy Exploration Co. Ltd., and *L. A. Pym*, A.M.Inst.Pet., general manager of Australasian Petroleum Co. Pty. Ltd., have recently been on a visit to the Papua-New Guinea permit areas of the latter company.

*E. Stokoe*, F.Inst.Pet., is now acting as sole representative on the Continent of B. and R. Redwood and is working from 21 Longue rue Neuve, Antwerp.

*A. R. Crew* has been appointed publicity manager of Monsanto Chemicals Ltd., and will deal with all matters concerning press relations, publicity, etc., from the company's new administrative offices at 8, Waterloo Place, London, S.W.1.

## ECUADOR AIR SURVEY

MAPS to be used in the development of the oilfields of the Anglo-Ecuadorian Oilfields Ltd., are in course of preparation by Hunting Aerosurveys Ltd. The maps will be on a scale of 1 : 10,000 over an area of 400 square miles and aerial photographs have been made by Aerofotos Ltd., a Colombian associate of the Hunting Group.

# ARE RESEARCH LABORATORIES FACTORIES?

*By* V. BISKE (Fellow)

"What shall I be?
You will be a Betwixt-and-Between"
J. M. BARRIE,
*Peter Pan in Kensington Gardens*,
Chap. II.

RESEARCH laboratories are often thought of as being in a class on their own, and those who work in them have frequently felt themselves to be slightly "different" from the "works". That this feeling of differentiation exists is undoubted; whether it is desirable is another matter, and probably most industrial scientists would feel that there is much to be said against any such distinction. There is little doubt that, up to the present at least, laboratories, and more especially research laboratories, have in many ways stood apart from the more mundane bread-and-butter departments. It is, however, very likely that research workers will have to come down from their "ivory towers" should the logical consequences follow from the recent decision of the Court of Appeal in the case of *Stanger* v. *Hendon Borough Council*.*

In this case a consulting engineer had set up, in what had been scheduled as a residential area, a laboratory for, among other purposes, the testing of concrete. In the course of ensuing legal proceedings, it was finally held that the particular laboratory in question was to be considered as an industrial building since it came within the definition in s.151 of the Factories Act, 1937.

Whilst, of course, the case was decided on its own specific facts, it would appear that the view of the Court was that since, in this case (taking into consideration the type of work carried out), the research laboratory was operated "for purposes of gain", it was from the legal standpoint a factory. From the report it would appear that one of the main operations, performed in this particular laboratory, was the manufacture of concrete specimens for testing to destruction, and on the results of these tests the consultant's report to his clients was made. On these facts the wording in s.151 (1) of the Factories Act, 1937, dealing with the making, breaking up, or demolition of any article, was one of the main points at issue; thus, in this particular instance, it must be assumed that a factor of considerable influence in the decision of the Court was that actual materials were made and subsequently broken.

Now in very many research laboratories, nothing is broken (intentionally, at least), but in few laboratories could it be said that nothing was made or manufactured. From the decision of the *Stanger* case, it will follow that, to bring the building within the Factories Act, such manufacture or making need not be for purposes of sale, as it is sufficient if it is for purposes of gain.

The question whether or not testing materials is part of manufacture for sale was considered by the House of Lords in 1931, in the case of *Grove* v. *Lloyds British Testing Co.*† In this case a portion of the factory was used for the testing of anchor chains, and the case was fought on an issue relating to the rateable value of the factory; it was decided that testing operations were not "factory purposes". Although of interest, it is therefore not strictly direct authority on the question whether or not a research laboratory is a factory, and in fact this case was not quoted in the *Stanger* case. A precedent which, however, was there discussed, was that of *Wood* v. *L.C.C.*‡ In this case, a kitchenmaid had injured her hand whilst chopping potatoes in a kitchen of a L.C.C. hospital. The potato chopper,

*[1948] 64 T.L.R. 164. †[1931] A.C. 450. ‡[1940] 2 K.B. 642.

which was mechanically operated, was not fenced, and the case against the hospital was brought on the argument that such lack of fencing was a breach of the Factories Act regulations. The Court, in the first instance, decided that the kitchen was a factory, but on appeal this decision was overruled, and it was held that the particular kitchen was not a factory within the meaning of the Act.

It is interesting to note that one of the arguments used by McKinnon, L.J., was that if the kitchen were a factory, s.70 of the Act would apply, and certain restrictions on the use of female and juvenile labour after 6 p.m. and on Sundays, would follow. It is, with respect, difficult to see why this particular line of argument was taken, since it is not usual to interpret statutes on the grounds of convenience. One of the points made by the learned Lord Justice was that it would be impracticable to apply s.70 to a kitchen and that hence a kitchen is not a factory. Although the impracticability is not so evident, it may likewise be said that, as well as s.70, other sections of the Act cannot, without the greatest inconvenience, be applied to a research laboratory. In the *Wood* case it was stated that "in construing an Act one is not to be deflected from giving it its proper meaning by looking at the absurd lengths to which the definition may drive one, but one can take into account the whole nature of the premises". Here these were a hospital, for the benefit of the inmates and staff of which the kitchen was run, and it was presumably felt that this was in every sense too far removed from a "factory" to be held to be one.

If the *Stanger* case is to be followed, and research laboratories (the majority of which, when owned by industrial firms, are, it must be admitted, operated for "purposes of gain", even if the gain is not immediately obvious) are deemed to be factories, then numerous consequences follow, some of which may be, to say the least, inconvenient.

It would mean that any unprotected machinery in the research laboratory would have to be fenced, in accordance with the strict provisions of the Act; also electrical potentials, and sometimes high ones are used for research purposes, would have to be conducted and shielded in a manner complying with electricity regulations. Whatever work she was engaged upon, a woman chemist would have to knock off sharp at the specified hours, unless exemption for that particular laboratory had been obtained from the Minister of Labour, by virtue of the powers granted to him by subsequent Acts. Whilst it would probably not be difficult to obtain such exemption, it would involve additional form filling and red tape. Hitherto, the position in this respect would appear to have been that works control laboratories have been treated as part of the factory; such an interpretation follows from the wording of s.152(4) which states that any woman is deemed to be employed in a factory who works therein (whether for wages or not) at anything incidental to or connected with, the process or article made or treated. Obviously the last phrase would cover the control testing of any substance made or processed in the factory, particularly if, as is almost invariably the case, the control laboratory is in the precincts of the factory.

Research laboratories, which are frequently separate from factories have, however, not usually been considered as coming within the Act.

Other points to be noted are the prohibition of Sunday work for certain types of employees, and possibly prohibition of eating in a place where work is carried out.

An example of the type of restrictions that might apply is the requirements of s.59 dealing with the employment of women in processes involving lead. In the case of a research laboratory this could involve enforcement of these regulations, if for instance a woman

chemist were making fuel blends containing T.E.L. Whilst in practice the precautions observed when using this material are at least as stringent as those laid down in s.59, the exact terms of that section might not always be convenient to apply to a laboratory and its personnel. (But see s.109 which, if we accept the term "process", which is not defined in the Act, to include laboratory operations, would already appear to cover the employment of women "in processes involving the use of lead compounds . . . in any place other than a factory as if the place were a factory".) Perhaps, however, such cases would, even if technically within the Act, be covered by the maxim *de minimis non curat lex*, otherwise it would seem that even an analytical laboratory would come within the scope of this section. (Except that it could probably be successfully argued that "process" signifies operations carried out on an industrial and not on a bench scale.)

It must, of course, be remembered that the entire scope of the Factories Act is restricted to places where people work by manual labour. This term has, however, in the Factories Act a wider meaning* than under the Employers' and Workmen's Act, 1875; in the latter case manual labour must be the main purpose for which a person is employed, whereas under the Factories Act manual labour may be merely incidental. The question whether or not a chemist is employed in "manual labour" was decided in the case of *Bagnall* v. *Levinstein*,† where it was held that he was not so employed. This case was, however, one under the Employers' Liability Act, 1880 (which adopts the terminology of the Employers' and Workmen's Act, 1875) and it is possible that, if the natural and ordinary meaning of this term were taken into consideration, the normal manipulations which every chemist carries out in the course of his work could be considered as "manual labour". Moreover, there is the question of the laboratory technician (e.g. the glass blower) where it would seem clear that he is employed in manual labour.

It does not thus appear that any general rule as to the position of research laboratories, which differ so much between themselves, can be drawn, each case depending essentially on its own special facts, but, if the Act were to be strictly applied it would appear that most research laboratories of an industrial type, and almost certainly those having "pilot plant" facilities, would come within the scope of the Act, whilst laboratories of a more academic nature and those devoted mainly to analytical work, would be outside its provisions, since even the *Stanger* case, where the operations as regards "making" and "breaking up or demolition of any article" were probably on a somewhat more extensive scale than is the case in many other laboratories, was described by Scott, L.J., as being a case on the border line, but in his opinion the deciding factor was that "the occupier of the premises was occupying them 'for purposes of gain' ". In the *Stanger* case the *ratio decidendi* would thus appear to be that where premises, used as a laboratory, and in which articles are made or broken up, are operated for gain, even if the gain be indirect, such as by payment for reports issued on the results of tests carried out in the laboratory, then such user brings the premises within the Factories Act. Presumably if a similar laboratory had been operated by, say, a university, the decision would have been different.

The position was concisely put in words used by Vaisey, J., in his judgement in the *Stanger* case, "To my mind, the building here in question is not a factory in the dictionary sense, nor is it a factory in the sense in which an ordinary man would use the word in ordinary speech. I am, however, satisfied that it is a factory as defined in s.151 of the Factories Act, 1937."

* See Maddock and Bellhouse, *The Factories Act*, 1937 (1st edition), at p. 327. †[1907] 1 K.B. 531.

# TO OVERSEAS MEMBERS

"Harry"

You are members of a large family of which the individuals have a great variety of interests widespread over the surface of the earth.

Your parents and a major percentage of the family are located around London. Others have settled throughout the length and breadth of the British Isles. You have settled in other lands.

Like most families during the war contact between individual members was spasmodic or lost. The ordered scheme of things became disordered. Your parents spent a certain portion of their time dodging part of the production of German steelworks.

With the cessation of steel exports from Germany came a new phase during which your parents had to wash the dishes, make the beds, and give a hand generally with the housework. It was the same in all families. The second item of conversation, possibly the first on the female side, was the servant problem. Can you wonder, therefore, that after the final washing up or the last piece of ironing your parents may not have been in the mood to sit down and reply to your mail by return of post.

On top of all that there was the spring cleaning. That took some time but you should just see the house now. It is all spick and span again with no dust behind the sofa or under the carpets.

A few weeks ago your parents were thinking about you. They wanted to get the family together again now that things had eased up and they did not want you to get the impression that you were being forgotten just because through an accumulation of housework they had missed a mail. So they had a word with one of your brothers—Harry to you—who was with you for a considerable number of years and is now with the family at home.

With his agreement your parents have nominated him to look after your interests. He is a Member of Council, where he can take up direct any questions on your behalf. He is also on the Branches Committee, the Publications Committee, and the Public Relations Committee, where he can deal with any suggestions made by you or any questions affecting you.

If you are a lone wolf with no one to support your application for membership, write to him. If you have any suggestions for the formation of new branches or for brightening up your meetings, write to him. If you have suggestions as to any particular type of article you desire to see in the publications, write to him. Remember, however, that he does not profess to be a magician and that he is dependent on the family for all articles which appear in the publications. If you have articles for publication, and such articles are always very welcome, route them through him.

He is all set to look after you. It is up to you to make full use of him.

You want his name and address! Right, here it is:

H. E. F. Pracy, B.A., "Shell" Refining and Marketing Co. Ltd., Heysham Refinery, Morecambe and Heysham, Lancs., England.

---

Copies of a report by the Underwriters Laboratories Inc. on Horton floating roofs for vertical steel oil storage tanks are available from the Chicago Bridge & Iron Co., 332 South Michigan Avenue, Chicago 4, Illinois.

# PETROLEUM GEOLOGISTS AT MANSON HOUSE

THE 18th International Geological Congress held in London during the latter part of August and the beginning of September brought together many petroleum geologists from every petroleum-producing country of the world. It also provided an opportunity for the Institute of Petroleum to entertain these petroleum geologists at a reception held at Manson House on August 30. Upwards of 80 attended and were received by the President, Mr E. A. Evans, and by Mr T. Dewhurst, Past-President. Several Members of Council were also present.

During the evening the company gathered in the lecture theatre and were formally welcomed by the President, who said:

"The Institute of Petroleum is proud to be associated with the International Geological Congress, therefore we are very happy to welcome you here this evening. We recognize and admire the great services which geologists have given to the discovery of petroleum in many parts of the world. Without their aid petroleum supplies could not have reached the amazing volume which every country in the world enjoys to-day. The influence of petroleum products upon world affairs cannot be overestimated. It can be stated that civilization could not have reached its present level without them.

"In this Institute we are privileged to have as corporate members geologists of no mean distinction. On my right I have Mr T. Dewhurst, whose fame in the field of geology is well known to all of you. The accurate balance of his mind has been of inestimable value to my Council, and I tell you with pride that he is one of our Past-Presidents. Professor V. C. Illing is one of our Vice-Presidents and Dr G. M. Lees has supported us in no mean way, and had Sir Thomas Holland, one of our Past-Presidents, been with us to-day he would have been President of your Congress.

"Modest as these men may be they have succeeded in impressing upon us the importance of geology, and the dignity and lofty aspirations of geologists. In fact I have come to view the geologists in this Institute as the mermaids amongst the herrings. In the more dramatic moments a geologist seems to stop at nothing. If an obstacle obstructs him he just blasts it, and often to satisfy his curiosity he resorts to creating a miniature earthquake. In the main, however, he does something grander, more magnificent, and more satisfying. The immense epochs of time are his playground.

"However highly competent a man may be in one branch of learning he can never be satisfied with one department of knowledge. Some seek a more comprehensive view one way, and others another. The broad horizon of petroleum has given adventure, lively interest, and even rewards to geologists, though I have no doubt that it has provided personal hardships and disappointments. Whichever way the pendulum swings he just carries on, fortified with the knowledge that should he discover or even suspect a fluid of any kind below ground the petroleum man will be on the spot just in case it might be petroleum.

"The petroleum family is so vast in its interests that to try to distinguish the individual conversations in a petroleum gathering is like trying to disentangle the smells in a fish market. To meet the needs of these various interests the Institute of Petroleum provides the focal point. We admit geologists chemists, engineers, and many other interested persons as corporate members. Although we are mainly a professional society we undertake co-operative

research, standardize methods of test for petroleum products, provide scholarships, and in general encourage education in petroleum affairs. Our interest does not terminate in corporate members for we have branches to cater for the wider needs of the people who are engaged in the petroleum industry. Lately we have introduced a new class of membership, designated Member-Company. This has been done to give the petroleum industry *in extenso* the advantages of corporate membership, to extend the wisdom of co-operative research, and to foster international agreement on all matters relating to the science of petroleum."

Mr Dewhurst, in supporting the message of welcome from the President, referred to the great success of the sessions of the Congress dealing with the geology of petroleum; also to the numerous geological excursions which showed that the British Isles constitute a veritable geological museum.

He then explained that the Institute of Petroleum was the first to be founded for the study, discussion, and dissemination of scientific knowledge pertaining to petroleum. The original list of Members of the Institute contained the names of many distinguished geologists, including Sir Thomas Holland, Dr David T. Day, Director of the United States Geological Survey, Professor de Böckh, Mr E. H. Cunningham-Craig, Dr T. O. Bosworth, and others. Professor Watts joined a little later, and was a Member of Council for many years. Geologists played a very prominent part in the early activities of the Institute, and many papers, published in the early volumes of our Journal, dealt with the geology of oil-producing countries. These activities and records provide a sound basis for the claim that the Institute had played a valuable part in establishing a high status for the profession of petroleum geologist.

Since the early days of the Institute the evolution of petroleum geology had been marked by several striking innovations and by ever-increasing specialization. Geophysical methods, photogeology, tectonical studies, micropetrology, micro-palaeontology, and even micro-palaeobotany had been enlisted as aids to exploration and stratigraphical correlation. In the realm of development geology, the introduction of core analysis, Schlumberger surveys, inclinometer and dipmeter surveys, bottom-hole pressure measurements, water-flooding, gas conservation and repressuring, and studies of dissolved, gas, gas-cap and edge-water drives, had created a whole new science and art of oilfield development.

Increasing specialization was inevitable and desirable but, as one of the older geologists, he hoped that a specialist in generalization would arise to effect a synthesis of all the accumulated data and disclose its full bearing on the old and main problems of the origin, migration, and accumulation of petroleum.

In conclusion, he pointed out that many years would elapse before the International Geological Congress would again be held in London, and extended a warm welcome to all present to pay further visits to the headquarters of the Institute whenever they happened to be in Britain.

Following Mr Dewhurst's speech, two films were shown, the first entitled "Ten Thousand Feet Deep," having been loaned by the Shell Petroleum Co. Ltd., and the second "The Gift of Green" by the Anglo-Iranian Oil Co.

Mr N. M. E. Schürmann, delegate of the Netherlands Geological and Mining Society and a member of the staff of the Bataafsche Petroleum Mij, expressed on behalf of the visitors their thanks for an enjoyable evening. The expression of thanks was supported by J. Harlan Johnson, professor of geology at the Colorado School of Mines and a delegate of the American Association of Petroleum Geologists.

# INTERNATIONAL GEOLOGICAL CONGRESS, GREAT BRITAIN, 1948

*By* T. DEWHURST (Fellow and Past-President)

AT the seventeenth Session of the Congress, held in Moscow in 1937, it was decided that the eighteenth Session should be held in Great Britain in 1940. Preparations were well in train when the Hitler war intervened, and the Congress was postponed *sine die*. In July 1946 the Lord President of the Council gave an assurance of Government support for the Congress, and subsequently approved the proposal that it be held from August 25 to September 1, 1948. General Organizing and Executive Committees were then formed, and Sir Thomas Holland, a Founder-Member and Past-President of the Institute of Petroleum, was appointed President of the General Organizing Committee and President-Designate of the Congress. Following his death in May 1947 he was succeeded by Professor H. H. Read, F.R.S., President of the Geological Society of London.

Owing to adverse economic and political conditions affecting so many countries after the war, and to the difficulties of travel, fears were expressed that it would be impossible to re-establish the Congress on a firm basis. Fortunately, the officers, and the members of the Organizing Committee, did not entertain these fears, and issued invitations to many countries and institutions, in some cases through official channels. Their diligence and ingenuity also solved the many difficult problems of organization. In the sequel, more than 1650 members registered, and the actual attendance constituted a record, and included twice as many overseas delegates and members as had attended any previous session of the Congress. The Governments of some fifty-six countries, and a large number of overseas universities, geological societies, surveys, institutions, and other scientific bodies were represented by delegations. In addition, some sixty universities, scientific societies and institutions in Great Britain were officially represented. The Congress was, in fact, the greatest gathering of geologists ever held at any time in any country.

The various meetings of the Congress were held in the Royal Albert Hall, the lecture hall of the Royal Geographical Society, the numerous lecture rooms of the Royal School of Mines and the Royal College of Science, and the Geological Museum. These splendid and spacious buildings provided a perfect setting for all the activities of the Congress.

The opening meeting was held in the Royal Albert Hall, and addresses were given by the Right Hon. Lord Addison on behalf of the Government, and by the Right Hon. Sir John Anderson, Honorary President of the General Organizing Committee. The delegates and members then settled down to the serious scientific work of

[*International News Photo*

*Even geological congresses have their lighter moments as is evident by the obvious enjoyment of Mr N. M. E. Schürmann* (left centre) *and Mr T. Dewhurst.*

the Congress, which was allocated to some twelve sections, each covering an important aspect of general or applied geology. Altogether some 389 papers were read and discussed. Those on general subjects dealt with geochemistry, metamorphism, sedimentation, ocean floors, earth movements and organic evolution, the geology of Africa, palaeontology, the evolution of man, etc.; while those on economic subjects dealt with the geology of petroleum, the geology and reserves of lead and zinc, the mineralogy of clays, the iron and other mineral deposits of many countries, and the results of applied geophysics.

The sectional meetings were well attended, and although many extra seats were provided in the large lecture rooms, it was often necessary for members to stand five or six deep. Indeed, some of the rooms were so crowded that ventilation seemed inadequate while lantern slides were being shown.

Space will not permit of reference to the work of more than one or two of the sections. In the past, fears have been expressed regarding world reserves of lead and zinc. Only a few years ago the best expert opinion was that the known reserves of these metals would be exhausted in fourteen years at the present rate of consumption. It is, therefore, fortunate that the estimate has now been raised to nineteen years for lead and to twenty-four years for zinc. The position will rapidly become very serious unless discoveries of new deposits of the ores of these metals keeps pace with consumption, or satisfactory substitutes are invented.

The section dealing with the geology of petroleum was most successful. A fascinating series of papers presented the salient geological features of the Middle East oil region, western Pakistan, and the Alexandretta Gulf basin; while another series dealt with the geology of the eastern Andes and the Atlantic coastal plain. Other papers dealt with the petroleum geology of parts of France, micropalaeontology, the significance of the world's deepest well, and the desirability of compiling a world atlas showing the relationship existing between surface evidences of structure and actual underground structures as proved by deep drilling. Another paper gave a detailed account of the latest methods of air survey, and the interpretation of geology from air photographs. Most of the papers were models of presentation, were followed with keen interest, and gave rise to profitable discussion.

The Institute of Petroleum invited the petroleum geologists attending the Congress to a Reception at Manson House on August 30, and an account of this function appears in this issue of the *I. P. Review*. The Anglo-Iranian and Burmah oil companies gave a luncheon at the Armourers' Hall which was well attended, and was followed by interesting geological exhibitions and demonstrations at Britannic House. The Burmah Oil Company Ltd. also gave a very successful tea party at the Hyde Park Hotel to all geologists interested in the geology of India, Pakistan, and Burma.

In addition to the sectional meetings of the Congress, several general meetings were held in the spacious lecture theatre of the Royal Geographical Society. Important addresses on "The Structural History of England and Wales" and "The Structural History of Scotland" were given by Professor O. T. Jones and Sir Edward Bailey respectively. A special lecture, illustrated by a remarkable and quite unique colour film, entitled "Paracutin and Mexico's Volcanic Area" was given by Dr. Pough, in collaboration with Dr. Reina and Mr. William Foshag. The volcano started its life on February 20, 1943, with a small eruption in a cornfield, and the film shows most striking and very close views of the ejection of volcanic material which in a few years piled up a volcanic cone some 500 metres high, and strewed the surrounding country

with volcanic bombs, ashes, dust, and successive lava flows. Some of the lava flows extend ten kilometres from the crater, and in places, successive flows have filled in valleys to depths of 100 metres. The film is a wonderful record of an unique event and, although the film was taken specially for the Congress, it is much to be hoped that it will be released for educational purposes.

In addition to the meetings of the Congress, some thirty-seven long geological excursions were arranged to demonstrate the general and economic geology of the greater part of Great Britain and eastern Ireland. Nineteen of these excursions were completed prior to the Congress, the remainder being undertaken subsequently. During and near to the dates of the Congress, a large number of whole-day and half-day excursions afforded members opportunities of visiting places of geological, archaeological, and historical interest in and within easy reach of London. In addition, non-geological tours were arranged to enable the relatives of members to visit cathedral cities, the English and Scottish lake districts, Shakespeare's country, the Wye Valley and mid-Wales.

Receptions were given by His Majesty's Government, the University of London, the Geological Society, the British Museum (Natural History) and other bodies.

In conclusion, the success of the Congress far exceeded all expectations, and it is fortunate that London was able to re-establish the Congress on a firm footing after the long hiatus caused by the war years.

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# THE DEVELOPMENT OF THE OIL EQUIPMENT INDUSTRY IN GREAT BRITAIN

*An Address by* H. de WILDE (Fellow) *to the Oil Industries Club*

THE Americans usually date the origin of the oil industry as about 1859 by Col. Drake's well in Pennsylvania. I would put it further back than that. I know the Chinese were drilling some 200 years B.C. They did not make their equipment, they grew it. It was mostly bamboo and, in the twenty-two centuries that have elapsed since then, the Chinese have not changed any of their equipment—it is probably exactly the same as it was originally.

The Western peoples are rather more impatient, and, to give you an idea of how the oil industry has grown since 1859, I would like to give world oil production in rather big units, units of one cubic kilometre (6300 million barrels).

The first cubic kilometre took 55 years to extract—from 1859 to 1914. The second cubic kilometre took nine years and was actually taken out by 1923. And from then on the time has gradually reduced until now we are taking one cubic kilometre out of the ground every two years, and the grand total at the end of 1948 will be about 10 cubic kilometres. This was all done with small holes dug in the ground and the oil industry is very proud of it. However, if we think of the eruption of Krakatoa, which threw out 8 cubic kilometres of rock in 24 hours, the efforts of the oil industry over some 89 years are puny compared with Nature.

Ten cubic kilometres is about two and a half cubic miles of oil from the world's oilfields to date.

The oil industry is the fourth largest industry in the United States. It is only exceeded in size by the automobile, the meat packing, and the steel industries. You will note that the automobile

industry could not have been developed without the steel or the oil and I doubt whether the meat packing industry could have existed without the steel industry. So you have a complete inter-dependence there of the different industries. At first the methods employed in the oil industry were comparatively primitive, but, as the oil industry grew, it is natural that allied with it an industry developed in the United States to supply it with equipment. The United States, you must remember, not only produces about 60 to 70 per cent of the world's oil but consumes that amount almost entirely domestically.

## Rotary Drilling Equipment

The first drilling equipment was mainly percussion and the first rotary table was constructed in 1899 but did not become an immediate success. It was not until about 1914 that the rotary began to find general application in oil work and at that time it was only considered suitable for drilling down to 1000 metres—3300 feet. All these things grew more or less like Topsy. The standard rig became heavier and heavier until the walking beam was 4 feet in thickness by 12 inches wide and 26 feet long—the largest that I know of. Later on they went in for steel. I remember building a combination standard tool and rotary in the Dutch East Indies in 1916 out of teak wood. The walking beam was the size just mentioned and the main sill 18 inches square and 32 feet long. Useful bits of teak!

As the rotary system of drilling is now most widely used in general, and exclusively used for deep drilling, I shall confine myself to the development of this equipment. Originally, the drill-pipe was used with the ordinary pipe thread and coupling connexion. A round trip was a lengthy and laborious procedure and many thread failures occurred. It is said that a standard tool driller, visiting a rotary rig, watched the laborious performance of unscrewing a large number of parallel thread connexions. The percussion tools were already using a tapered joint which required only a few turns to unscrew, and the standard tool driller remarked: "Why don't you use a tapered joint like ours?" Apparently little was done about it until it came to the notice of a well-known oilfield equipment man who patented what is known as the rotary tool joint and collected $1 on every tool joint made under his licence.

Originally, the rotation was imparted to the drill pipe by the rotary table, by means of "grip-rings." These consisted of four hardened rings, equally spaced by means of blocks through which right- and left-hand screws were run. The rings were clamped tightly on to the drill pipe by means of these heavy screws, so that the pipe could move down through them, but the rotary movement of the table would be imparted to the drilling string. At that time, no one had thought of the simple expedient of using a square stem running through a square split bushing in the rotary machine and so getting a positive drive. The first of these positive drive stems, called "kellies" or "grief stems", was evolved in 1914.

Another source of trouble was the right-hand connexions above the rotary table, which of course had to be watched constantly as they tended to unscrew. It was not until 1920 or so that left-hand screw connexions became universal for the equipment used above the rotary table.

The first casing heads were made by Trout and Butler. I understand that they discussed the design on the following lines: Trout said to Butler: "What thickness shall we make the flange?" and Butler said: "About one inch, I guess."

"And how many bolts shall we put in?"

"About a dozen bolts."

These heads were used quite successfully for a number of years, but with the greater critical demands these things have to be considered on a much more scientific basis nowadays, or trouble will be encountered.

The Americans have not been the only ones to come with new ideas. We have the Schlumberger electrical logging equipment, by means of which the formations in the well can be determined very quickly without coring. The hydraulic coupling, used in diesel-driven rigs, was originally a German invention, greatly improved by a British concern and, in its latest form, making drilling with diesel engines as flexible as with the steam engine. The hydromatic brake also works on a principle originally invented in Britain.

### Production Equipment

On the production side, sucker rods were made of wood with steel ferrules at the ends for screwing together. Later they became steel rods with welded-on pins and boxes and then came the upset rod, where the pins or pin and box were integral parts of the rod itself, thus eliminating welding.

Regarding well pumps, the ordinary cup type pump was the first, but as wells became deeper the cups were unable to do the job properly and were displaced by the plunger pump and by tube pumps like the fluid packed pump. Later, special pumps like the Reda and Kobe, which have their working parts at the bottom of the well, were developed.

### British Manufacture

This is a very brief and by no means comprehensive sketch of history. In 1939 I came to England to try and get manufactured in Britain equipment which had never been made here before. In 1939, owing to some pre-occupation here with war work, only a few smaller firms could be induced to undertake this special work. The first of many things I started with were the well-pumping units, of which about 240 were made in the first year and a half. Then the White Paper came along and closed things down. When the war ended we started again. In oilfield equipment there is quite a code of fashion. One day one particular article is suitable and a few days or months later ideas have changed and something else is wanted. If a new industry is to be started in Britain to make oilfield equipment, it is necessary to have equipment which will be of more or less permanent requirement and will not be changed at frequent intervals. In 1939, or in 1945 rather, there were only two firms who made a general line of oilfield equipment, although there were some others who specialized on some particular line, like sucker rods and so forth.

The amount of material needed for the devastated oilfields and the amount wanted to renew equipment in existing fields to bring production up was enormous and quite beyond the scope of the few firms who were working on it, so that new ones had to be brought in. In this, I think, there has been considerable success. I was looking over the figures recently and I found that out of £2,136,000 worth of orders which were placed in Britain in 1947, £1,950,000 worth was for equipment which would normally have been ordered from the States.

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An attractive booklet recently issued by the American Cyanamid Company is entitled *Chemical Additives for Petroleum Lubricants*. In non-technical language with simple illustrations it describes additives and their function. Copies are obtainable from Cyanamid Products Ltd., Brettenham House, Lancaster Place, London, W.C.2.

# THE ENGINE PERFORMANCE OF LUBRICANTS*

*By* C. G. WILLIAMS (Fellow).

THE specification of an engine lubricant normally includes a number of items which, to a large extent, determine the initial behaviour of the lubricant in an engine, especially from the physical standpoint. Thus, the viscosity limits determine the effect of the lubricant on the ease of starting at low temperatures and the capacity to maintain an oil film at working temperatures. Unfortunately, however, actual performance in an engine plays havoc with many of these properties and, in addition, introduces requirements for which so far, no adequate laboratory methods have been developed for their prediction. This means that, however useful and essential laboratory specification tests may be, they are certainly not adequate. It is, for example, possible for two oils to meet an existing specification, one of which is satisfactory in service and the other unsatisfactory. The obvious deduction from all this is that, while the pudding may have the required appearance, density, consistency, and so on, it is necessary to apply the final test of eating it in order to judge its excellence.

The general question of selecting laboratory engine test methods for assessing the performance of lubricants is a very big one, on which quite a good deal has been written—and the subject is still in its infancy—but I do not propose to do more than just touch on it in the present paper. In general, the particular features of service performance giving rise to specific troubles are imitated, usually in an aggravated form. Such tests may, for example, be run at continuous high temperatures, continuous low temperatures, or under cyclic conditions involving a mixture of both.

The main purpose of this paper is to discuss some of the things which happen to the oil and to the engine in service, with particular reference to the formation of deposits, which usually have a controlling influence on lubricant performance.

One of the main themes is that there are two main causes of engine and oil deposits, namely:

(1) Oxidation of the oil itself.

(2) Contamination resulting from the supply to the engine of air and fuel with their resulting products of combustion.

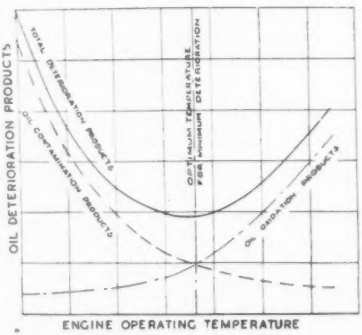


*Fig. 1.—Effect of engine operating temperature on lubricating oil deterioration products.*

While the first can be attributed to the properties of the lubricant, the second is an extraneous factor to which the lubricant has to submit. The combined effect of extraneous contamination and of oil oxidation can be very complex and is still imperfectly understood. Probably the most important operating factor is that of engine temperature, the effect of which is illustrated in Fig. 1, which shows diagrammatically the effect of

* Paper read before Northern Branch, Institute of Petroleum, on January 12, 1948

temperature on the two kinds of contamination, and on their combined result. Oxidation of the lubricant will obviously increase with temperature, the effect becoming rapidly more pronounced at the higher temperatures. On the other hand, the general importance of contamination from combustion products increases as the temperature is reduced, owing to the bad effect of low temperatures on combustion and also because the water of combustion condenses in the engine below certain temperatures. Thus, there are two general kinds of deterioration with exactly opposite tendencies in relation to engine temperature, and their combined effect is shown diagrammatically by the upper curve. In general, very low or very high temperatures give most deposits though, as will be seen, the kind of deposits which are formed at high temperatures differ very considerably from those formed at low temperatures. There is an intermediate temperature range, obviously the desirable one, giving minimum deposits.

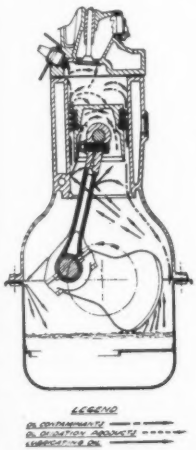

*Fig. 2.—Oil oxidation products: Peroxides, Aldehydes, Organic acids, Resins, Asphaltenes.*

Oil contaminants —*Burnt products (water, carbon dioxide). Partially burnt products (carbon monoxide, resins, hydrocarbons, soots). Unburnt liquid fuel. Sulphur compounds (sulphur dioxide, sulphur trioxide, hydrogen sulphide). Lead compounds (lead chloride, lead bromide, lead oxide, lead sulphate). Inorganic acids. Metal salts. Mineral matter (fuel ash, dust).*

Now to amplify the varied and difficult conditions under which an oil has to function, and the contaminating influences to which it is exposed.

Fig. 2 shows a sectional view of an engine. The general level of temperature of the oil in the crankcase does not normally exceed 100° C, an exception being certain aero engines, in which temperatures up to, say, 120°C may be experienced. Oxidation occurs slowly at such temperatures which, therefore, are not particularly harmful to the lubricant, and if the oil did not exceed such temperatures and there were no other extraneous contaminating influences, a good lubricant would give satisfactory service almost indefinitely. The oil is, however, sprayed on to the cylinder walls and underside of the piston, where it reaches much higher temperatures, normally as high as 200° C. Even higher temperatures maybe reached in certain regions, e.g., 250° to 300° C.

Such temperatures result, initially, in the formation of light and relatively unstable products such as peroxides, while continued oxidation produces aldehydes, organic acids, and heavier polymerization products such as lacquers and resins, and ultimately materials which are insoluble in the oil. The oxidation products which are formed are mentioned in Fig. 2, and their effects will be discussed shortly. This oxidation occurs while the lubricant is spread thinly on the cylinder walls and on the underside of the piston. A small portion of the oil leaks past the piston into the combustion chamber, where most of it is burned and passes out through the exhaust, but some of it may be "carbonized" on the surface of the combustion chamber. A small proportion may also be oxidized and carbonized *in situ* on certain parts of the piston, but most of the oxidized drainings go back into the crankcase, contaminating the main oil supply.

Apart from oxidation of the lubricant, there is, as already mentioned, an

entirely different cause of deterioration for which the lubricant is not directly responsible, and which originates in the combustion chamber.

Fuels consist mainly of a complicated mixture of hydrocarbons which, if they are burned completely, produce only water and $CO_2$. Where combustion is not complete—and it very rarely is perfectly complete—partially burnt fuel products will be formed, such as aldehydes, peroxides, organic acids, and heavier oxidation and polymerization products such as resinous materials, or even free carbon or soot.

In gasolines there is usually only a small amount of sulphur, while in diesel fuels there are much larger amounts, e.g., 1 per cent or even more. This sulphur normally burns to sulphur dioxide or sulphur trioxide, while at low temperatures sulphuric acid may be formed.

In the case of gasoline engines the fuel will frequently contain tetraethyl lead, about 1 cc per gallon for motor spirit and up to 4·8 cc per gallon for aviation spirit. The ethyl fluid contains a scavenger, normally ethylene dibromide, the function of which is to combine with the lead liberated in the combustion chamber to form lead bromide, which has a relatively high volatility, so that, theoretically, it is not deposited on combustion chamber surfaces. Without such a scavenger the lead would oxidize to PbO, which is relatively involatile and would be deposited in fairly large quantities within the combustion chamber. In actual fact, while the lead scavenger is fairly effective, certain quantities of lead oxide, as well as lead bromide, are formed within the combustion chamber. In addition, some of the lead may combine with sulphur from the lubricating oil to form lead sulphate.

There is also contamination arising from dust in the inlet air, and from ash in certain residual diesel fuels.

It is, therefore, obvious that there are plenty of possible contaminating sources originating from the combustion chambers of both diesel and gasoline engines. The seal provided by the piston in the cylinder is never perfect, i.e., there is normally a leakage of gases from the compressed gases in the combustion space past the piston into the crankcase. These blow-by gases will carry with them some, or all, of the contaminants I have described. On their way past the piston they may exercise a marked effect on the character of piston deposits and exercise a determining effect on the condition of the lubricating oil in the crankcase and on its general performance in the engine.

The various kinds of deposits and the influence they may have on engine performance will now be discussed in greater detail.

*Deposits in Combustion Chamber*

In considering deposits in the combustion chamber, it is necessary to distinguish between engines running on unleaded fuel, and engines, more especially aircraft, which operate on highly leaded fuels. With unleaded gasolines it can be stated that combustion chamber deposits originate, in the main, from burning of the lubricating oil. Their main constituent, in fact, is carbon, by which name they are usually described. Apart from carbon they usually contain a small amount of ash and oily matter.

The quantity of carbon formed is affected very considerably by a number of engine factors. For example, a high oil consumption will tend to give high combustion chamber deposits. Combustion chamber temperature and engine operating load are other important factors. A low temperature will not give rise to the formation of carbon, while a high temperature will result in the burning-off of existing deposits. There is, therefore, an intermediate temperature range within which carbon deposits occur most rapidly. Another important fact is that carbon deposits

tend to increase with running time up to a certain maximum value, beyond which further deposits are burnt off.

While the bulk of carbon deposits come from the lubricating oil, it should be pointed out that carbon from the fuel may contribute its quota. In the case of a diesel engine, bad combustion gives rise to soot, which may augment combustion chamber deposits quite considerably. In the same way, the operation of a petrol engine with an over-rich mixture will give rise to soot.

There is no reliable method of indicating the tendency of an oil to deposit carbon in engine combustion chambers. While a carbon residue test may provide a rough indication, it may be misleading under certain engine conditions.

It is implied by the foregoing that combustion chamber deposits are affected by the use of leaded fuels. In fact, on aircraft engines using 4·8 cc of lead per gallon of fuel, more than half the total deposit in the combustion chamber normally consists of lead compounds, e.g., lead bromide, lead oxide, together with metallic lead. Such deposits, as we shall see, may be much more harmful than carbon, and their presence certainly cannot be attributed to the lubricant. The quantity and type of such lead deposits will, to a large extent, depend on engine temperature and, as in the case of carbon deposits, there is a tendency for lead deposits to be removed by engine operation at high temperatures.

The two main effects of combustion chamber deposits are on (*a*) engine knock and (*b*) spark plug reliability.

Owing to their poor thermal conductivity, deposits tend to raise the general temperature level of the combustion chamber surfaces, while their presence obviously reduces the volume of the combustion chamber and thereby increases the compression ratio. The result, in both cases is to encourage detonation or knock. These effects may

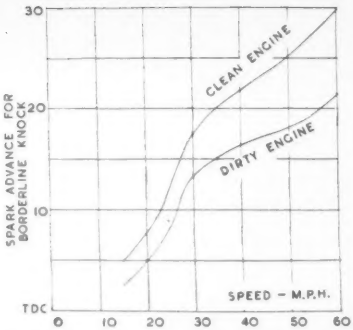


*Fig. 3.—Effect of combustion chamber deposits on detonation limited performance.*

tend to become more important as compression ratios are increased and combustion chambers become smaller.

Fig. 3[6] illustrates the effect of carbon deposits on knock in a motor-car engine. The border-line spark advance (i.e., the maximum permissible spark advance if knock is to be avoided) is plotted against engine speed for (*a*) a clean combustion chamber and (*b*) a dirty combustion chamber. It is evident that the ignition would have to be retarded to avoid knock with the latter; the effect of the carbon deposits in this particular instance is equivalent to using a fuel with an octane number reduced by 8.

The other main result of deposits in the combustion chamber is the fouling of spark plugs. Fig. 4[7] illustrates the sort of thing which can occur. The *left*-hand plug had been used in an engine with a low oil consumption, and the *right*-hand plug with a high oil consumption. The effect of the high oil consumption in aggravating fouling is evident. In this particular instance a leaded fuel had been used and some of the deposits were formed of lead bromide, lead oxide, and metallic lead. Such lead deposits, when they are present, are more harmful than the carbon, since they have a relatively high electrical conductivity, which may

result in a "short" across the insulator. Carbon or lead deposits may also accumulate on the electrodes and bridge the spark gap.

*Ring Groove Deposits*

Reverting to Fig. 2, a portion of the oil which is splashed on to the cylinder walls may remain sufficiently long on certain hot parts of the piston to oxidize to the point at which it forms a deposit *in situ*. This may occur in the piston ring grooves, where deposits may accumulate (*a*) behind the rings and (*b*) on the sides of the ring grooves. In the former case the lateral freedom of the piston rings will be restricted, possibly resulting in scuffing, while in the latter case ring-sticking will result. The condition of an engine which continues to operate with stuck rings will, in general, deteriorate rapidly because the piston seal will have been spoilt, resulting in (*a*) an increase in oil consumption, and (*b*) a leakage of hot gases from the combustion chamber, with an increase in piston temperature. On high output engines, particularly aircraft, this may result in detonation or pre-ignition, with complete piston, and possibly engine, failure. The result may be less disastrous on an engine of lower output but sufficiently serious to cause high oil consumption and other engine troubles. This is particularly true of diesel engines which, in general, are susceptible to ring-sticking.[1]

Ring-sticking, on both petrol and diesel engines, is largely the result of oil oxidation at high temperatures. The deposits which accumulate in the ring grooves consist mainly of "carbon" with small quantities of lacquer, "oxyacids", and asphaltenes which tend to bind the deposits and make them "tacky". These may be formed, not only by high temperature oxidation of the lubricant, but as a result of bad combustion in diesel engines. Lacquers are normally hard at room temperature but soften at piston temperatures. This explains the quite common occurrence of "cold-sticking" of piston rings—the rings are free as long as the piston is hot but they are stuck by the hardening of the lacquer as the engine cools. The reverse process may occur, viz.: the rings may free themselves when the lacquer melts as the engine is warmed up.

*Fig. 4.*

When a leaded fuel is used there may be quite an appreciable quantity of lead compounds present in the ring groove deposits, e.g., 20 per cent.[7]

The main operating factor controlling ring-sticking is the ring belt temperature and, in general, the higher the temperature the greater the tendency for ring-sticking to occur. Ring-sticking will also be very markedly affected by a number of engine design features, which it is not the purpose of this paper to discuss.

One of the main reasons for requiring oxidation stability in lubricants for high output engines is to ensure adequate resistance to ring-sticking. During the war, aviation oils were subjected to actual engine ring-sticking tests in order to ensure that this requirement was met. Unfortunately, no simple laboratory oxidation test has yet been developed for predicting the engine ring-sticking performance of lubricants. This is partly attributable to the complexity of the problem, and to the influence of products of combustion.

In the diesel engine, soot arising from bad combustion may contribute to ring groove deposits. In this connexion, the sulphur content of diesel fuels may have an important influence on ring-sticking. Fig. 5[5] shows the extent of ring belt fouling plotted against sulphur content

for both light and heavy engine loads. The detrimental effect of sulphur is most apparent under heavy load conditions, when soot is being formed, the deposition of which is, apparently, encouraged by the presence of combustion products of sulphur.[3]

In the petrol engine, as already mentioned, lead compounds may form an appreciable proportion of the deposits. It is of interest to mention, in this connexion, that certain lead compounds have a detergent or anti-ring-sticking effect so that, on balance, the presence of lead in the fuel may be beneficial from the standpoint of ring-sticking.[7]

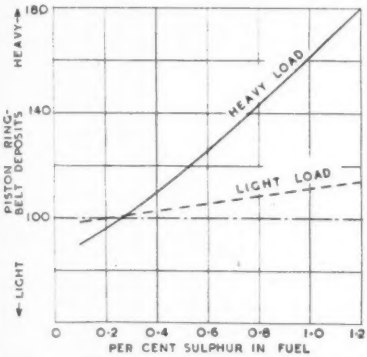


*Fig. 5.—Effect of sulphur on piston ring-belt deposits.*

The clogging of scraper rings lower in the piston, which may result in an increase in oil consumption, may be attributable, not only to oxidation of the oil *in situ*, but also to the accumulation of sludge and solid matter which is contained in the bulk oil supplied to the piston. In certain cases, this clogging of scraper rings and oil drainage holes, resulting in high oil consumption, may be the limiting factor in determining the overhaul life of an engine.

*Piston Lacquer*

Another kind of deposit which occurs on the piston is lacquer, or varnish, on the piston skirt and under the piston crown. This lacquer is the result of oxidation of the lubricant *in situ* and is illustrated in Fig. 6, which compares two pistons operated with detergent and non-detergent oils, respectively. Lacquer on the piston skirt may not be at all harmful unless it builds up to the extent that it reduces the clearance between piston and cylinder. Deposits accumulating on the underside of the piston crown may tend to fall off into the crankcase, contributing to the general contamination of the crankcase oil, with possible harmful results elsewhere. Lacquer on the piston skirt, while usually the result of oil oxidation, is undoubtedly aggravated by products resulting from bad combustion, especially in diesel engines.

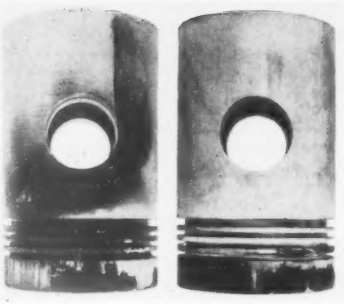

*Fig. 6.*

*Acids and Corrosion*

As already mentioned oil-soluble acids are one of the early oxidation products of lubricants. Normally, such acids are of high molecular weight and fairly innocuous but there have been cases where corrosion troubles have occurred owing to the attack on certain bearing materials by such acids. The bearing materials most liable to such attack are cadmium/silver, cadmium/nickel, and copper/lead. Cadmium alloy bearings were used on certain aero engines during the war and it was necessary to ensure that oils for

these engines did not produce acids corrosive to cadmium, and a laboratory corrosion test was developed for this purpose. In actual fact, an oxidation inhibitor (tributyl phosphite) was used on certain oils to prevent the formation of these acids, and thereby to stop corrosion. In general, however, cadmium alloys are no longer used in bearings and little corrosion trouble has been experienced with lead.

There is another source of acids, viz.: from the combustion chamber; partial products of combustion, combined with water condensing at low engine temperatures, produce low molecular weight acids (such as acetic) which are, to a large extent, insoluble in oil. In diesel engines, such acids may be augmented by sulphuric acid from the combustion of sulphur in the fuel, and by carbonic acid from the $CO_2$ in both petrol and diesel engines. All these acids are essentially the result of engine operation at too low a temperature — which suggests the obvious method of preventing their formation. In general, they are non-corrosive to bearing alloys, but they may tend to corrode ferrous materials such as valve covers, oil pans, valve springs, etc.

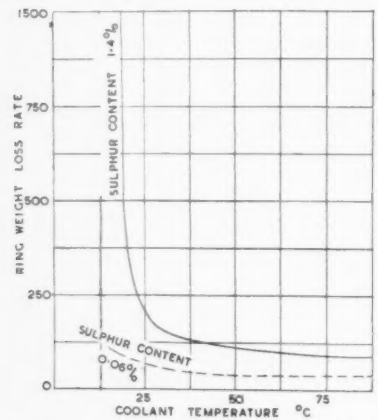


*Fig. 7.—Effect of coolant temperature and fuel sulphur content on engine wear.*

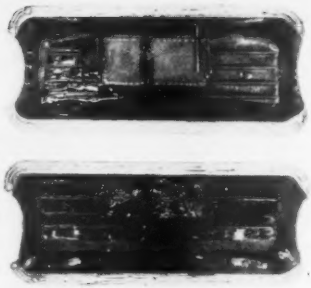

*Fig. 8.*

Fig. 7[7] shows the very marked influence on cylinder wear of corrosive products obtained with sulphur-rich fuels. The effect of sulphur is obviously greater at low engine temperatures, i.e., below the dew point when sulphuric acid is formed.

*Sludge* (Fig. 8)

Crankcase sludge is of two main types, viz.: (*a*) low-temperature sludge and (*b*) high-temperature sludge.

I have already mentioned that water is one of the main constituents of blow-by gases and that, at temperatures below the dew point, viz.: about 50°C, it condenses on cylinder walls and in the crankcase. This water, combined with "carbon," oxidation products and partial combustion products from the fuel, forms the unpleasant black sludge which settles out in relatively quiescent parts of the engine, viz.: on valve covers, oil pans, etc. As already mentioned, this type of deposit often contains water-soluble acids and will tend to cause rusting of ferrous surfaces. Apart from this, sludge deposited on crankcase surfaces is relatively harmless and may only be a nuisance if it interferes with the pumpability of the oil or causes clogging of oil filters. The obvious remedy for this type of sludge is to avoid any unnecessary operation at low engine temperatures and, where very intermittent operation is required

in cold climates, to endeavour to keep the engine as warm as possible and to shorten the warming-up periods during which water can be condensed.[2]

A warm engine will also tend to minimise the formation of partially burnt fuel products caused by the chilling of the combustion on the combustion chamber walls. The volatility of the fuel and the mixture temperature are also important factors. The greater the volatility the less the liability to form such products, and this applies to both gasoline and diesel engines.

In the diesel engine bad combustion may arise from a number of causes, e.g., injector fouling, overloading of the engine, the use of a fuel having an abnormally low cetane number. Under such conditions large quantities of unburnt products, soot, etc., will be liberated and will contaminate the oil film. There is little doubt that this form of contamination is a major problem in the lubrication of diesel engines.

The rate of contamination due to poor combustion will obviously be independent of the type of lubricant. Fig. 9[1] shows the amount of soot in the lubricant plotted against engine load. More soot is liberated as the load is increased, resulting in greater contamination, and this contamination is the same for three different lubricants.

Some interesting experiments have recently been carried out in the U.S. on the effect of mixture strength on fouling of a petrol engine and the results are summarized in Fig. 10.[2] Over-weak and over-rich mixtures both encourage sludge in the crankcase—in the former instance, probably through imperfect combustion and in the latter through the liberation of soot.

The same figure shows exactly the opposite trends for scraper ring deposits. The over-rich mixture may result in increased dilution and in a scavenging effect.

The influence of sulphur in causing corrosion problems and in aggravating ring belt deposits has been mentioned. The amount of sulphur in motor gasoline is normally so small as to have a negligible influence, but in diesel fuels the sulphur content may be 1 per cent, or higher, and the products of combustion of sulphur may have a marked effect in promoting sludging. It has been mentioned that $SO_3$ has a rather obscure, but none the less important, effect in encouraging the coagulation of carbon and oxidation products and their deposition in the engine. This effect will also be apparent in relation to crankcase sludge.

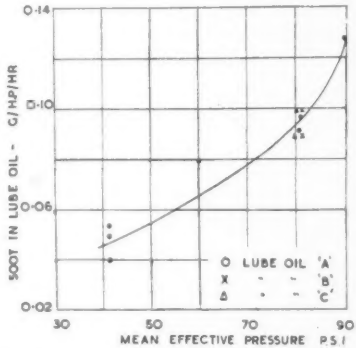


*Fig. 9.—Effect of m.e.f. and lubricating oil on soot accumulating in the crankcase oil.*

The tetraethyl lead in motor or aviation spirit produces, as has been shown, a mixture of lead salts. Strangely enough, their influence in the upper belt of the piston appears to be beneficial on the whole. At any rate, other things being equal, ring-sticking is less likely to occur with a leaded fuel than with an unleaded fuel, possibly because tetraethyl lead has a mild anti-oxidant effect. In other respects, however, the accumulation of lead salts in the crankcase is detrimental, particularly in an aircraft engine where relatively large amounts of tetraethyl lead are used and where certain components are

particularly susceptible to certain troubles. These troubles arise from the high density of the lead salts, the result being that they are centrifuged out at high rotational speeds. This may occur in crankshaft oilways, where normally quite half the total deposit is lead, the other half being carbonaceous. This "plugging" of oilways may interfere with oil circulation, though cases where this has actually happened have been very rare, so that it is not looked upon as being a particularly serious problem. Associated, however, with many aero engines is a centrifugal clutch which is operated by the pilot when changing from one supercharger gear to another

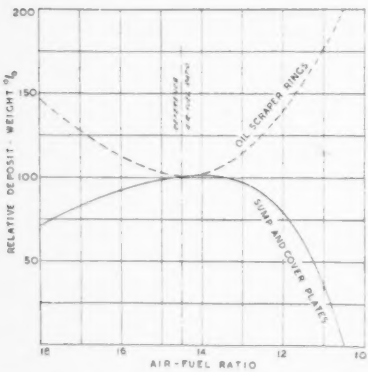


*Fig. 10.—Effect of mixture strength on deposits.*

as the aircraft climbs. This clutch rotates at a very high speed and considerable trouble has been experienced owing to the accumulation in it of deposits which consist largely of lead compounds. In fact, a centrifugal cleaner has sometimes been fitted with the object of extracting such deposits, but unless such a centrifuge is of the full-flow type and also applies a centrifugal field greater than that provided by the clutch, there will still be trouble due to the centrifuging of deposits in the clutch itself.

*Fuel Dilution*

Dilution of the crankcase oil will obviously occur mainly at low engine temperatures, e.g., when starting from cold. With the petrol engine subsequent operation at high temperatures tends to vaporize a substantial proportion of the diluent but this evaporation obviously does not occur to anything like the same extent with diesel fuels. In both types of engine, dilution tends to reduce viscosity, but unless it is high, dilution is of relatively minor importance. In general, the reduction in viscosity will be counteracted by the tendency for oil viscosity to increase owing to oxidation and to the accumulation of suspended matter.

A recent survey has shown that fuel dilution in petrol engines varies from 0 to about 10 per cent, with an average of about 4 per cent.[8] In diesel engines a somewhat similar amount of dilution may take place.[1]

*Ash Content*

The inorganic matter accumulating in the lubricating oil consists of wear products (e.g., iron, aluminium, etc.) dust from the atmosphere, lead compounds from leaded petrols, and ash from residual diesel fuels, where such fuels are used. When a leaded petrol is used, the main constituent of the inorganic matter in the used oil may be lead compounds, but in other cases the main constituent will usually be $Fe_2O_3$. The circulation of this material through the engine may increase wear, and will certainly do so if the silica content is appreciable. On the other hand, some constituents of the inorganic materials may be innocuous in this respect.

*General Discussion*

Sufficient has been said to indicate that engine design and operating conditions have a very marked effect on oil contamination and on deposits within

the engine. One of the main factors is that of the engine temperature, and it has been pointed out that too low a temperature will result in excessive contamination from fuel products, while too high a temperature will result in excessive oxidation of the oil itself. Each kind of deterioration will produce its own specific troubles. A good deal can be done by the designer and operator to minimize such troubles, e.g., low temperature sludge can be minimized by thermostatic temperature control and by crankcase ventilation.[4] Ring-sticking, which results from high-temperature oxidation, can be reduced by the use of wedge piston rings, and so on.

Contamination resulting from bad combustion is an important factor, and can be minimized by the use of correct mixture strength in petrol engines, and, in diesel engines, by maintaining the injector in good condition, avoiding overloading, and using the correct grade of fuel.

There is a good deal of evidence that the use of an efficient oil filter will not only have the obvious effect of keeping the oil cleaner, but will also reduce deposits on engine surfaces. This is especially true if the filter elements are cleaned or replaced at fairly frequent intervals.[7]

The frequency of oil changes is another important factor. There is a good deal of evidence, both from the laboratory and from service, to indicate that the more often the oil is changed the cleaner the engine.[4] There is, of course, an economic limit to the frequency of oil changes. A recent survey has shown that in public service and transport vehicles the mileage between oil changes ranges from 1,000 to 14,000.[8] There may, of course, be good reasons for this range, depending on the type of engine and service, but one cannot help feeling that it is, to a large extent, due to the personal whim or indifference of the operator. Some operators have established, as a result of their own experience, an optimum frequency of oil drainage, but in many cases there can be no doubt that more frequent oil changes would be beneficial.[4] One of these days it may be possible to apply fairly straightforward tests to a crankcase lubricant which will indicate without question its suitability for further use, but that stage has not yet been reached.

The petroleum technologist is, of course, interested in the part which the lubricant plays in giving satisfactory engine life. While this subject is outside the scope of this paper, sufficient has been said to emphasize that an oil

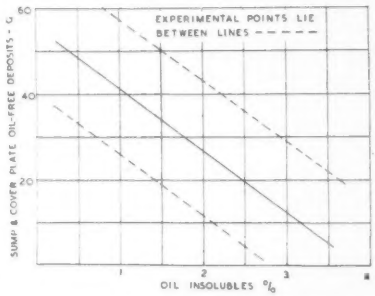


*Fig. 11.—Relationship between engine deposits and oil insolubles.*

requires two main characteristics—firstly, resistance to oxidation, and, secondly, ability to hold in solution or suspension the various contaminants to which it is exposed. Anti-oxidant additives can be used to improve the former, and detergents or peptizers to improve the latter. Peptizing or detergent additives appear to function by preventing the coagulation of particles to form bigger particles which would be more easily deposited. These particles are mostly of about one or two microns in size, and a recent estimate has been made that the surface area of such particles in a gallon of used oil is of the order of 22 sq. ft.[6] It is conjectured that the additive is adsorbed on the surface of these particles and prevents

their coagulation, or it may prevent their deposition on metallic surfaces.

It is also obvious that an oil should not be judged adversely because it is dirty. In fact a dirty oil may be one which is doing its job properly by holding dirt in suspension instead of allowing it to be deposited in the engine. This is illustrated in Fig. 11[2] which shows engine deposits plotted against oil insolubles for a number of different lubricants tested under standardized conditions. In general, it will be noted that the higher the oil insolubles the cleaner the engine.

The petroleum technologist is very actively engaged in doing what he can to improve engine lubricants. Just what is required of him is becoming clearer as a result of research and experience in the field. There can be little doubt, however, that the subject of oil deterioration and of engine deposits is a very complicated one which is still imperfectly understood.

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## A LUBRICATION COURSE

A COURSE of five lectures on Lubrication at the Sir John Cass Technical Institute, will commence on Thursday, February 3, 1949, at 6.30 p.m. Lectures and lecturers are: Theory and General (*Lt.-Col. S. J. M. Auld*), Production (*C. Hull*), The Testing of Lubricating Oils and Greases (*C. S. Windebank*), Industrial and Marine Lubrication (*R. S. Teale*), and Automotive and Aviation Lubrication (*O. T. Jones*). Fee for the course is 10*s.* and enrolment forms are obtainable from the Principal of the Cass Institute, Jewry Street, Aldgate, London, E.C.3.

## FORTHCOMING MEETINGS

### INSTITUTE MEETINGS

**Detergency of Carbon Black in Hydrocarbon Solution.** F. H. Garner and A. R. W. Baddeley. At 26 Portland Place, London, W.1, 5.30 p.m. (tea 5 p.m.), November 10.

**Evaporation Losses at Marketing Installations.** R. L. Sarjeant. At 26 Portland Place, London, W.1, 5.30 p.m. (tea 5 p.m.), December 8.

**The Measurement of Kinetic Boundary Friction.** F. T. Barwell and A. A. Milne. At 26 Portland Place, London, W.1, 5.30 p.m. (tea 5 p.m.), January 12.

*SCOTTISH BRANCH*

**Engine Tests of Lubricating Oils.** R. Stansfield. At Heriot-Watt College, Edinburgh, 7.30 p.m., November 26.

*SOUTH WALES BRANCH*

**Pressure Vessels.** A. C. Vivian. At Britannic House, Llandarcy, 5.30 p.m., November 2.

*LONDON BRANCH*

**Aircraft Gas Turbines.** S. A. W. Thompson. At 26 Portland Place, London, W.1., 6 p.m. (tea 5.30 p.m.), November 23.

**Film Show—Atomic Physics.** At 26 Portland Place, London, W.1., 6 p.m., (tea, 5.30 p.m., December 21.

### MEETINGS OF OTHER SOCIETIES

**Report on Heavy-oil Engine Working Costs, 1946–7.** Diesel Engine Users' Association, at Caxton Hall, London, 2.30 p.m., December 16.

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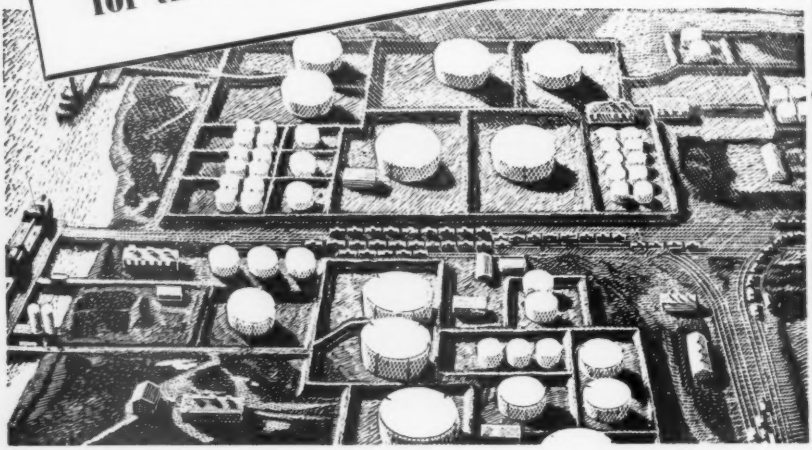

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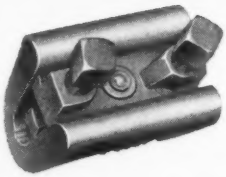

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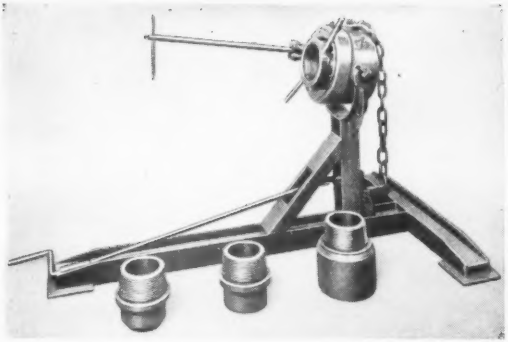

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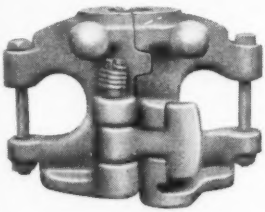

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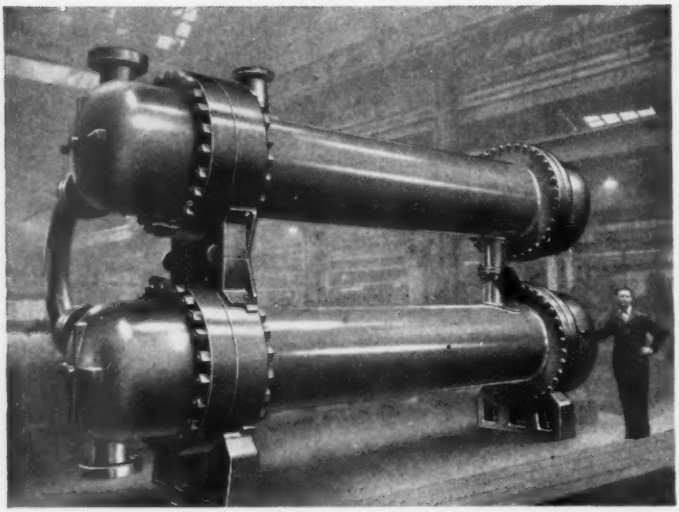

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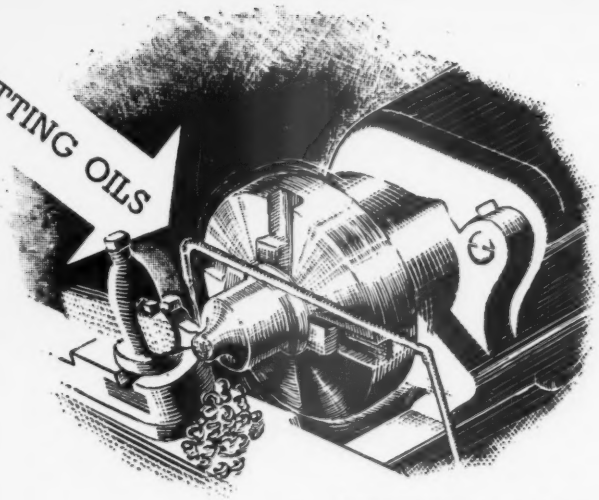

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